

## THE CHEMISTRY OF ELECTROSTATIC PRECIPITATION

P. L. Feldman and K. S. Kumar  
Research-Cottrell  
Somerville, NJ

Keywords: Electrostatic precipitation; corona; electrical  
breakdown; resistivity; chemical conditioning

### ABSTRACT

Electrostatic precipitation is a leading means of particulate emissions control for large industrial and utility plants. It effects collection of the particulate matter by charging the particles in a corona discharge and causing them to migrate to a grounded collecting surface under the influence of an electric field. At first it may appear that this process is strictly electrical in nature, but in reality the chemistry of the process is just as important, if not moreso, as the electrical aspects are to the efficiency of the process. The important chemical effects are seen primarily in the gas phase chemistry as it influences electrical breakdown, or sparking, and particle surface chemistry as it influences conductivity and cohesivity. This paper presents examples of the use of chemical methods to enhance the precipitation process including the use of chemical conditioning agents to improve particle conductivity or cohesivity or to increase gas breakdown strength. Also discussed are specific effects of sulfur, sodium, carbon and various metals in determining the viability of electrostatic precipitation in a given application. A section is also devoted to a discussion of the use of corona discharge to promote chemical reactions for air pollution control.

### THE ELECTROSTATIC PRECIPITATION PROCESS

Electrostatic precipitation is a leading means for the control of particulate emissions from large industrial and power generation sources. It is capable of very high particulate removal efficiencies, including the control of the submicron particulate fraction. The electrostatic precipitation process is different from other mechanical means of particulate control, such as filters and cyclones, in that it uses electrical forces to separate the particles from the gas stream. These electrical forces are applied by exposing the particles to a corona discharge, thereby charging them electrically, and then placing them in a zone of high electric field strength. The resultant electrical force, proportional to the product of the particle charge and the field strength, moves the particles towards a grounded collecting surface where they are held until periodically rapped into hoppers for disposal. Modern industrial precipitators use the single-stage design which accomplishes the corona discharge and electric field functions simultaneously in a single geometry consisting of high voltage discharge electrodes placed between grounded collecting plates. The discharge polarity in these precipitators is negative. The discharge electrodes themselves are either small-diameter wires or more rigid bodies with points or sharp edges. A sharp radius of curvature

is necessary to concentrate electric field strength to allow corona discharge.

Although electrostatic precipitation is electrophysical in nature, the process efficiency and viability are strongly influenced by other scientific disciplines, especially gas and surface chemistry. In fact much of the original development work of the precipitator was carried out by chemists and metallurgists. Dr. Frederick Cottrell is credited with developing the first practical electrostatic precipitator in the early 1900's. The importance of chemistry in electrostatic precipitation can be understood by looking more closely at some of the performance-limiting aspects of the process, namely gas-phase breakdown, dust layer breakdown and particle reentrainment. Enhancement of the precipitation process can then be achieved by altering the system chemistry toward more favorable conditions.

#### ELECTRICAL BREAKDOWN OF THE GAS PHASE

Electrical breakdown of the gas phase as manifested by sparking limits the operation of the precipitator by imposing a maximum to the voltage which can be applied to the discharge electrodes, thereby limiting the power input to the precipitator as well as the field strength and the supply of corona-generated ions necessary to the process. Since precipitator efficiency can be correlated with power input, this limitation is very important. The levels of voltage and corona current at which sparking will occur is determined by gas density and electrode spacings as well as the chemistry of the gas flowing through the precipitator. In the corona zone, electrons are emitted from the discharge points and move toward the grounded electrode under the influence of the electric field between the discharge electrode and the collecting plate. As they lose their initial energy they tend to attach to gas molecules they encounter on the way, forming negative ions which then travel at much lower velocities toward the grounded electrode, resulting in a more controlled corona current. Gas molecules differ in their receptiveness to attachment of electrons. Nitrogen for example is not receptive. Therefore in pure nitrogen no ions are formed and the current is totally electronic, resulting in high current (because of the high electron velocities) and breakdown at voltages only slightly above corona start. The precipitation process is not practical under these circumstances.

For effective electrostatic precipitation, small amounts of electronegative gases must be present in the gas stream to attach the electrons and, through their lower ionic mobility, provide controlled corona current over a wide range of voltage before breakdown occurs. Such gases include oxygen, water, ammonia, sulfur dioxide, many organic vapors and others. Normal industrial flue gases contain adequate amounts of electronegative gases so generation of stable corona is not usually a problem. However, there are situations in which gas conditioning can be employed to reduce the net ion mobility and achieve more stable operation. An important example is precipitation at low gas density. Such applications include high temperature operations such as precipitators on fluid cat cracker exhaust in the petroleum industry. These precipitators normally operate at about 700°F and

frequently are limited by premature breakdown because of the low gas density. Addition of ppm amounts of ammonia is found to remedy the situation and allow operation at higher power input levels, thereby restoring efficient operation.

In other applications the addition of percentage amounts of water vapor can have significant benefits to electrostatic precipitation by allowing operation at higher voltage and power input levels because of the net reduction of ionic mobility. Practical increases in power input of 20% or more can be achieved in this way.

#### ELECTRICAL BREAKDOWN OF THE DUST LAYER

Another important performance limitation encountered by electrostatic precipitators is the electrical breakdown of the dust layer deposited on the collecting electrode. This condition arises when the resistivity of the dust layer is high. Generally when the resistivity is above  $10^{11}$  ohm-cm, electrical breakdown of the dust layer occurs before gas-phase breakdown. Dust layer breakdown is caused by the development of a high voltage gradient across the dust layer which exceeds the breakdown strength of the gas in the interstices of the dust layer. The voltage gradient is due to current flow through the layer, and is equal to the product of resistivity and current density. As resistivity increases, the allowable current before breakdown decreases, and, in extreme cases, operation of the precipitator is seriously impaired. Dust layer breakdown may manifest itself as premature sparking or as back corona. Back corona is a phenomenon in which a stable discharge of positive ions originates from the dust layer because of the high voltage gradient present there. The positive ions then tend to neutralize the negative particle charge achieved by the forward corona and thereby defeat the particle collection process.

Dust layer resistivity is dependent on the chemical composition of the dust and its temperature. For coal combustion flyash, several models and rules-of-thumb exist for relating flyash resistivity to ash composition, gas chemistry and temperature. For example a computer model developed by Southern Research Institute uses a large database to derive correlations for resistivity with virtually all the constituents of flyash. In addition there are many indices which have been published in the literature for relating various key components to resistivity. Examples include the alkali-silicate index relating resistivity to the ratio of sodium + potassium to silica + alumina; the Soviet index which uses the ratio of silica + alumina times ash content to moisture + hydrogen times sulfur content; the Bureau of Mines oxide index which uses the ratio of calcium + magnesium oxides to sodium oxide + sulfur trioxide; and many more. Also it is generally true that coals high in sulfur content produce ashes which are not of high resistivity. The point to be made is that the chemical composition of the dust to be precipitated determines its resistivity, and therefore determines whether or not the precipitator will have difficulty in operating effectively.

Temperature determines the mode of electrical conduction through the layer; at higher temperatures, e.g. above 400°F, volumetric

conductivity of the particles is controlling, and, at lower temperatures, e.g. below 300°F surface conductivity is controlling. In the transition range between about 300°F and 400°F a maximum in resistivity usually occurs. For power generation applications, flue gas temperature is normally around 300°F and, depending on ash composition, may be subject to high resistivity problems. Although it may appear that an easy solution is to either raise or lower the temperature of operation of the precipitator, this is not necessarily a practical solution. Lowering the temperature may result in acid dew point problems, and operation at higher temperature, though sometimes effective, carries with it other problems including the possibility of the sodium depletion phenomenon. Sodium depletion refers to the migration of sodium out of a thin sublayer of ash next to the collecting surface under the influence of the electric field at high temperature. The resulting sodium-poor layer, for many ashes, is itself highly resistive and presents the same high resistivity limitation the high temperature operation was intended to solve. The sodium depletion problem, however, has been found to be treatable by the addition of sodium compounds to the coal feed, although this is objectionable to many boiler operators.

An effective remedy for high resistivity and one that is practiced widely is chemical conditioning of the flyash. Chemical conditioning is effective in enhancing the surface conductivity of the ash and is thus generally used at temperatures of 300°F and below. Sulfur trioxide is the most used conditioning agent. The addition of ppm levels of sulfur trioxide to the flue gas can reduce resistivity out of the problem range by depositing a conductive layer of sulfuric acid on the ash surface. Not all ashes are easily conditioned by  $SO_3$ , however. For example the acidic Eastern bituminous ashes are more difficult to condition, often requiring higher levels of  $SO_3$  to be effective. On the other hand the alkaline Western coal ashes are easily conditioned by low ppm of  $SO_3$ . To improve the conditionability of the Eastern ashes it has become common to consider the use of dual conditioning, using low ppm levels of ammonia injection in the flue gas in addition to the  $SO_3$ . The effect of the ammonia is probably to increase the pH of the ash surface so that it is more receptive to the acid.

Although most commonly used, sulfur trioxide is not the only conditioning agent found effective for reducing resistivity. Others include sulfonic acid, sulfamic acid, ammonium sulfate and bisulfate, sodium carbonate, triethylamine, and various proprietary chemicals. In some cases moisture addition alone is effective.

#### PARTICLE REENTRAINMENT

Proper operation of an electrostatic precipitator involves periodic rapping of the collecting plates to jar loose the collected dust and allow it to fall into the hoppers for subsequent removal. Before the collected dust is finally removed from the precipitator, however, it is subject to reentrainment back into the gas stream by three mechanisms: scouring of the dust off the collecting surface by the gas flow itself; electrical reentrainment caused by inductive reversal of charge on the

collected dust because of inadequate electrical current; and reentrainment induced by the rapping blow itself. The effect of reentrainment is to reduce the net collection efficiency of the precipitator. This can be a serious limitation in achieving modern high efficiency particulate control requirements in a reasonably sized precipitator.

The reentrainment problem can be greatly reduced by agglomeration of the particles on the collecting surface. This is because the agglomerates will tend to cake and fall to the hoppers more readily than the non-agglomerated fine particles. Also the agglomerates, because of their larger size, are more easily recollected in the remaining precipitator than the fine particles. It has been found that certain chemical additives are effective in promoting this desired agglomeration by enhancing the surface cohesivity of the particles. Some of these are ammonia, dual injection of ammonia and sulfur trioxide, moisture, sodium sulfate and others. Through use of these chemicals, reduction of reentrainment results in a marked decrease in emissions from the electrostatic precipitator. It is interesting to note that the precipitator's chief rival for high-efficiency particulate control, the fabric filter, also benefits from conditioning to increase particle cohesivity; the benefits to the fabric filter include higher collection efficiency and reduced pressure drop because of the formation of a more porous filter cake.

#### CORONA CHEMISTRY

The region immediately surrounding the corona discharge point on the precipitator's discharge electrode is a region of intense electron activity. Electrons are emitted with high enough energy to create reactive species such as OH and O radicals when colliding with the constituent gas molecules. These radicals in turn can initiate reactions leading to the production of ozone and the oxidation of various flue gas components, e.g. NO and SO<sub>2</sub>, therefore presenting the possibility of gaseous pollutant control by corona initiated reactions. Various investigators have realized this potential and work is ongoing to develop practical corona systems for the control of SO<sub>2</sub> and NO. EPA and others are investigating the use of corona for VOC destruction, claiming destruction of benzene, toluene and other organics at very high efficiencies.

Normal electrostatic precipitator configurations are far from optimum for taking advantage of corona chemistry. The active corona region occupies only a small fraction of the volume of the interelectrode space. Therefore the opportunity and time for exposure of the gaseous components to the active species is not adequate for good removal. Changes away from normal precipitator design have to be made to evolve into a practical contactor for the purpose of gaseous pollutant control. Electrode spacings have to be reduced to increase the fraction of volume occupied by the active species; very sharp discharge points have to be used to concentrate the electric field strength and deliver high energy electrons; and pulse energization should be used to maximize the applied discharge voltage.

Further work is needed to develop the use of corona initiated reactions for gaseous pollutant control. It will not be done in a conventional precipitator design. Attention will also have to be paid to the energy requirement for achieving high levels of pollutant removal. Some of the reported work indicates that this requirement may be high depending on the pollutant to be removed.